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AN IMPLEMENTATION EXPERIMENT: WORK FORCE ESTIMATION MODELS AND --ETC(U)
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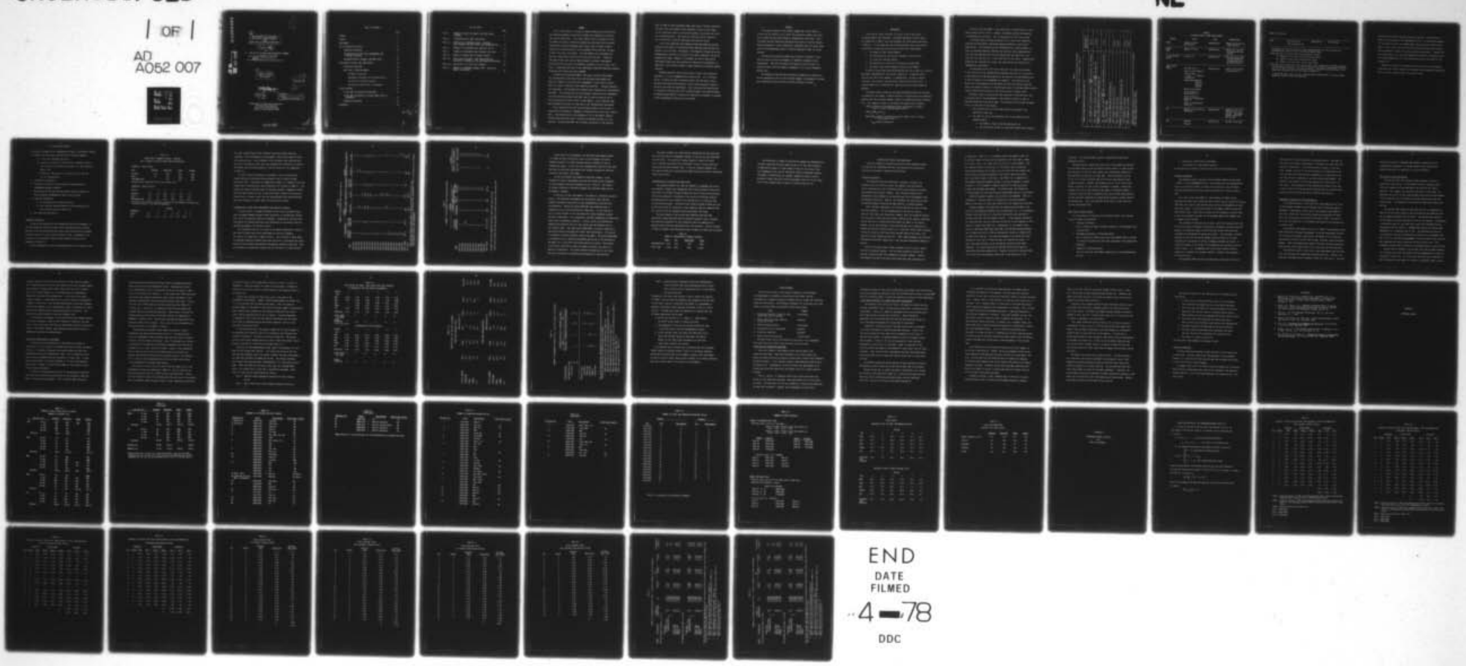

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AN IMPLEMENTATION EXPERIMENT: WORK FORCE ESTIMATION MODELS AND WORK FORCE SCHEDULING ALGORITHM.

FINAL REPORT

for

U.S. ARMY NATICK RESEARCH AND DEVELOPMENT COMMAND

Contract No. DAAG17-75-C-0017

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SUMMARY

This is the latest in a series of reports dealing with the difficult and important problem of work force planning and scheduling in military food service facilities. It has been shown in earlier research [1] that the number of workers required to prepare and serve meals and to perform the necessary sanitation depends upon factors such as number of meals, duration of a serving period, the time between serving periods, the type of meal, and worker utilization. The requirements vary throughout the day with a major peak occurring during the noon time meal. Therefore, the above factors were used to develop models to predict requirements by period of the day (prior to breakfast, breakfast, prior to lunch, etc.). Also, a scheduling algorithm [2] was developed to determine employee schedules which most efficiently met hourly demands.

The work force estimation models were used to predict requirements for the Pease Main dining facilities; the estimated requirements were modified slightly by the dining hall management to obtain hourly requirements for input to the work force scheduling algorithm . Proposed schedules were generated. The proposed cook schedules were implemented for approximately two weeks. The proposed food service attendant schedule was not implemented since the existing schedule used fewer hours by making extensive use of part time workers and split shifts to meet demand. A work sampling study was performed during the last nine days of the implementation experiment.

It was found that the work force estimation models could be used in conjunction with managerial judgement to determine hourly work force requirements. Statistical tests on the goodness of fit of the models, however, indicate that additional work is required if improved accuracy is to be obtained. Possible additional work includes re-analysis of the existing

data in terms of tasks performed rather than types of worker, obtaining more data (but less extensive work sampling) to cover a wider range of the significant factors, and using the models to evaluate facilities on a nation-wide basis. The later work could be used to identify a set of facilities from which additional data would be useful.

It was also found that the scheduling algorithm generates optimal schedules with respect to minimizing excess employees when regular work patterns are to be used. Accordingly, the schedules followed during the implementation resulted in a savings of two cooks compared to the period preceding the study. However, if a manager can hire to meet hourly requirements (which was the situation for food service attendants), an algorithm is not necessary because a human scheduler can generate optimal schedules.

Although additional work could be done to improve the scheduling algorithm, it is not recommended with high priority. As it currently exists, it should be used to schedule workers (skilled and/or union) who must have regular work patterns; efforts should be made to identify areas for use with this requirement. Also, the algorithm should be used in conjunction with the work force prediction models to establish bounds on employee needs before a contract for food service attendants is awarded so that unreasonably high bids can be avoided.

PURPOSE

The primary purpose of the research summarized in this report is to test and to evaluate a set of work force prediction models and a work force scheduling algorithm through an implementation experiment. Both the models and the scheduling algorithms were covered in earlier reports. Another objective is to gain additional information that will guide future uses of the methodologies and will identify meaningful areas for future research.

The work force prediction models were tested to determine if they could be used by dining hall managers to determine reasonable hourly requirements. They were evaluated with respect to service level on a subjective basis and with respect to goodness of fit using a Kolmogorov-Smirnov Test.

The scheduling algorithm was evaluated by comparing its schedule to the one developed by the civilian contract manager; the comparison includes hours expended and the uniformity of shifts assigned to workers.

BACKGROUND

In an earlier report by Davis, et al [1], a set of work force estimation models were developed. The models developed in their report are summarized in TABLE I with the parameters for these models described in TABLE II. It was found that the following factors were statistically significant in explaining the variation in work force requirements:

1. The number of meals served (MEALS)
2. The utilization of food service attendants, hereafter KPs, in a cook type function (KPUSE)
3. The duration of a serving or a non-serving period (HRS)
4. The type of meal being prepared or being served (MFACT)

A total of seven models were developed that met the criteria of variation explained, reasonableness, and relative simplicity. A separate model is used for the type of day (weekday or weekend day), the type of period (serving or non-serving), and the worker classification (cook or KP). A suitable model was not developed for cooks during non-serving periods on weekends.

The models predict productive workload (designated breaks are included as productive); the number of people required is obtained using the predicted quantity and the Fractional Manpower Cutoffs for Computing Military Standards [3]. The response variable in the models are based on the following:

$TEMP_{ijk}$=Theoretical estimated work force requirement for worker class i on day j during quarter hour k

$TEMP_{ijk}=AMP_{ijk} \bullet P_{ijk}$

Where AMP_{ijk}=Actual work force on duty of worker class i on day j during quarter hour k

P_{ijk}=fraction productive

As can be seen from TABLE I, the coefficient of determination is quite good (ranging from 63 to 96%). However, the models were not validated by an implementation experiment. This is the purpose of the current study.

In another report by Chong and Giglio [2], a work force scheduling algorithm was developed to determine employee schedules to meet hourly requirements. The algorithm utilizes methodology for integer programs in order to determine employee schedules that minimize excess employee hours such that each employee works five contiguous days per week with a full time shift of eight hours or a part time shift of four hours. Computational experience was reported; but, again, the algorithm was not tested via an implementation experiment.

The Pease Main dining facility at Pease Air Force Base was selected as the location for the implementation experiment due both to its proximity to the University of Massachusetts and to the University of New Hampshire, and to the willingness of the management to cooperate. The proximity to the University of New Hampshire was desirable since the work sampling team was drawn from graduate students in the Whittemore School of Business Administration (some of whom had participated in the earlier study of January 1976).

The major concern associated with the selection of Pease Main was that it had been used in the development of the predictive models so that an unbiased evaluation could not be made. This concern was alleviated following a visit to the site for two reasons:

1. The staffing levels for both cooks and KPs had changed since the earlier study; and,
2. The range for two of the parameters used in the models had also changed; namely,
   a. The number of meals served had decreased, and
   b. The utilization of KPs in a cook type function had increased.

TABLE I

SUMMARY OF PREDICTIVE MODELS FOR FOOD SERVICE PERSONNEL

DEFINITION OF FACTORS IS CONTAINED IN TABLE II

NUMBER OF COOKS DURING SERVING PERIOD MFACT ON:	Coefficient of Determination
(M1) $\text{WEEKDAY}=3.09+.179\cdot\text{MEALS}\cdot\text{MFACT}\cdot\text{HRS}-\text{KP}\cdot\frac{\text{KPUSE}}{100}\cdot(.475\cdot\text{MFACT}\cdot\text{HRS}-.708\cdot\text{MFACT})$	85.14%
*(M2) $\text{WEEKEND}=5.12-1.29\cdot\text{HRS}+1.36\cdot\text{MFACT}-.609\cdot\text{KP}\cdot\frac{\text{KPUSE}}{100}+.168\cdot\text{MEALS}\cdot\text{HRS}$	63.00%
**NUMBER OF COOKS DURING NON-SERVING PERIOD MFACT ON:	
(M3) $\text{WEEKDAY}=-1.15-.640\cdot\text{KP}\cdot\frac{\text{KPUSE}}{100}\cdot\text{MFACT}+1.43\cdot\text{MFACT}\cdot\text{HRS}+\text{MEALS}\cdot(1.33-.416\cdot\text{HRS})$	71.5%
(M4) NO ACCEPTABLE MODEL	
NUMBER OF KPs DURING SERVING PERIOD MFACT ON:	
(M5) $\text{WEEKDAY}=.376+1.30\cdot\text{MEALS}+.081\cdot\text{KPUSE}$	94.41%
*(M6) $\text{WEEKEND}=.909+1.95\cdot\text{MEALS}$	96.08%
***NUMBER OF KPs DURING NON-SERVING PERIOD MFACT ON:	
(M7) $\text{WEEKDAY}=1.70+1.28\cdot\text{MEALS}$	72.36%
*(M8) $\text{WEEKEND}=1.47+1.76\cdot\text{MEALS}$	93.61%

*Model developed for dining facilities that have three meal periods on weekends.
**No "After Dinner" period for cooks.
***No "Before Breakfast" period for KPs.

TABLE II

CATEGORIZATION OF WORK LOAD FACTORS

FACTOR	UNITS	TYPE	DESCRIPTION
Meals	Number of Meals per hundred	Quantitative	*Meals served during a meal period
HOURS HRS	Number of Hours	Quantitative	**Hours in a serving or between serving period
KP UTILIZATION KPUSE	Percent (%)	Quantitative	***Utilization of food service attendants in preparation and serving functions
MEAL FACTOR MFACT	Serving Period Cook to Order-MFACT=2 Cook to Order and Preprepared -MFACT=3 Preprepared-MFACT=1 (Dinner) MFACT=2 (Lunch) Non-serving Period Prior to Cook to Order-MFACT=1.5 Prior to Cook to Order and Preprepared-MFACT=3 Prior to Preprepared-MFACT=2.5	Quantitative	Type of meal served or to be served
KP	Number of Food Service Attendants	Quantitative	Number of KPs to be utilized in a work period. (Developed from KP models M5, M6, M7, M8
DAY	Weekday Weekend	Qualitative	Period of the week

TABLE II continued

TIME	Serving period Off-serving period	Qualitative	Work period

*The number of meals to be used in "non-serving periods" for KPs are from the preceding meal, and for cooks from the subsequent meal.

**Serving hours for meals should be extended to include:

a) BREAKFAST--1/4 hour before and 1/2 hour after

b) LUNCH--1/2 hour before and 1/2 hour after

c) DINNER--1/2 hour before and 1/4 hour after

***The Dining Hall Supervisor must rely on their "best judgement" to obtain estimates for this work load factor. The KP contract and a few direct observations of worker activities should provide reasonable estimates. The KPUSE values utilized in this study were obtained from the data shown in Appendix D.

It should be noted that a factor is categorized as qualitative if its occurrences cannot be placed in order of magnitude.

Although other factors remained essentially constant, the decision was made to use Pease Main as the implementation site. An additional drawback for Pease Main was that the weekend models for both cooks and KPs do not apply. This is due to the fact that the entire operating period at Pease Main on weekends is taken as a serving period by the models. Although this is not the actual case, the break between the breakfast serving period and the second weekend meal is of such short duration that the models do not recognize it.

None of the concerns cited above apply in the case of the scheduling algorithm since it only requires that suitable hourly demands be determined. This, of course, could be done in a variety of ways.

THE IMPLEMENTATION PROCESS

The process followed in this implementation study is outlined as follows:

1. Meeting with dining hall and food service contract managers
   a) Discuss the implementation plan,
   b) Establish procedures for obtaining the information and/or data required to estimate the parameters for the predictive models, and,
   c) Establish a time table for the acquisition of data and for the implementation.
2. Estimation of parameters.
3. Prediction of work force requirements and determination of recommended employee schedules.
4. Meeting with dining hall and food service contract managers to review schedule recommendations and to finalize same.
5. Schedules implemented
   a) for one week prior to data collection
   b) work sampling study performed for nine consecutive days from 19 March through 27 March 1977
6. Data reduction and analysis

PARAMETER ESTIMATION

In the initial meeting with the appropriate food service managers, it was determined that the type of meal served, the operation hours and the duration of the serving periods during each serving period had not changed from the time of our initial study during early 1976. Consequently, the estimates of the parameters, MFACT and HRS remained the same and are summarized in TABLE III.

At this same meeting it was also determined that the utilization of KPs

TABLE III

COMPARISON OF PARAMETER VALUES: ORIGINAL BASE (ASSUMED FOR PREDICTIONS) AND IMPLEMENTATION

PARAMETER: MEALS SERVED

MEAL:	MIDNIGHT	BREAKFAST	LUNCH	DINNER
ORIGINAL	100	280	480	380
BASE*	72	172	400	299
IMPLEMENTATION	--	167	406	298

*Average values observed from 23 Jan.-22 Feb. 1977

PARAMETER: KPUSE (percent)

PERIOD:	2	3	4	5	6	7
ORIGINAL	25.3	5.9	20.8	21.7	17.1	7.8
BASE*	30	10	25	25	20	10
IMPLEMENTATION	39.1	4.9	36.3	24.3	35.5	25.5

*Estimates from original study were scaled up by approximately 5% based upon interviews with D.H. and Contract managers

	PERIOD						
PARAMETER	1	2	3	4	5	6	7
MFACT	1.5	2	3	3	2.5	1	1
HRS	1.25	3.75	1.5	3.5	1.5	2.25	1

in a cook related function had increased since the original study was conducted. Precise estimates of the parameter, KPUSE, would require a small work sampling study. Since estimates of this parameter were obtained from the data of the January 1976 study, new estimates were obtained by increasing the former values by approximately 5%; the new values are also summarized in TABLE III.

In order to obtain estimates of the number of meals served by meal period, data were collected by Pease personnel from 23 January through 22 February 1977. These data are summarized in TABLE A.I in Appendix A and the values used in obtaining work force predictions are included in TABLE III. The results are based on average values of the data included in Appendix A except that data were omitted for days on which the normal schedule for the day was altered; and, in several cases, data for selected meals were omitted because they were outside of a normal range for the given meal period.

DETERMINATION OF WORK FORCE REQUIREMENTS AND EMPLOYEE SCHEDULES

As noted earlier, the models developed for work force estimation apply only for weekday (Monday through Friday) operations at the Pease Main dining hall due to the operation mode on the weekends. Consequently, the work force requirements for weekend operations were determined via discussions with the appropriate managers (see Tables IV and V).

The estimated values for the inputs to our models (summarized in Table II) were used to predict work force requirements by period for weekdays. The results are summarized in TABLES IV and V. Also included in these Tables are aggregate employee schedules which were used prior to and during the study along with the schedules generated by the employee scheduling algorithm. They are presented for comparative purposes and are discussed in a later section.

TABLE IV

SUMMARY OF REQUIREMENTS AND SCHEDULES FOR KPs

	WEEKDAY				WEEKEND		
	REQUIREMENTS		AVERAGE NUMBER SCHEDULED BY		REQUIREMENTS	AVERAGE NUMBER SCHEDULED BY	
TIME	PREDICTED BY MODEL	INPUT FOR ALGORITHM	ALGORITHM	KP MGR.	INPUT FOR ALGORITHM	ALGORITHM	KP MGR.
0530-0600	6	2	2	2	0	0	0
0600-0930	6	6	6	6	5	5.5	5
0930-1000	6	6	6.6	7	5	6.5	5
1000-1030	6	6	6	6.4	5	6	5
1030-1130	11	12	12.6	11.8	10	10	10
1130-1400	11	12	12.6	12.2	10	10	10
1400-1430	9	9	11	10.2	10	10	10
1430-1500	9	8	8	7	5	5	5
1500-1530	10	8	8	8	5	5	5
1530-1700	9	8	8	8	5	5	5
1700-1730	9	8	8	8.8	5	5	5
1730-1800	8	8	8	7.8	5	5	5
1800-1900	8	8	9.8	8.8	5	5	5.5
1900-2000	(3)*	3	3	3.2	1	1	1
2000-2200	(1)	1	3	1	1	1	1
2200-2300	(2)	2	3	2	2	2	2
2300-0130	(3)	3	3	3	2	2	2
0130-0200	(3)	3	3	3	1	2	1.5
0200-0230	(2)	2	3	2	1	1	1.5
TOTAL HOURS	672.5	637.5	691	652	192	199	194
Paid Hours			652	618.5		188	183.5

Table entries denote average number of people assigned at the given time.
*The time after 1900 is not covered by the models; the requirements listed in parentheses are skeleton requirements given by the DH Managers.

TABLE V

SUMMARY OF REQUIREMENTS AND SCHEDULES FOR COOKS

	WEEKDAY				WEEKEND	
		AVERAGE NUMBER SCHEDULED			AVERAGE NUMBER SCHEDULED	
TIME	PREDICTED REQUIREMENTS	RECOMMENDED	USED FOR STUDY	USED PRIOR TO STUDY	FOR STUDY*	PRIOR TO STUDY
0530-0730	3	3	3	4.5	3	2.5
0730-0900	3	3	4	4.5	3	2.5
0900-1030	7 (4)	4	4	4.5	3	2.5
1030-1400	5	5	5	6.1	3	3.5
1400-1530	4	4	4	4.1	3	3.5
1530-1600	4	4	4	4.1	3	3.5
1600-1730	4	4	3	4.1	3	3.5
1730-1800	4	4	4	5.1	3	4.5
1800-1900	4	2	2	2.6		2
1900-2000	1	1	1	1		1
Total Hours	297.5 (275)	265	265	321.75	75	84.5

*On March 19 and 20 additional National Guard Cooks were utilized.

Table entries denote the average number of people assigned at the given time.

In the case of KP requirements, our predicted requirements (column 1 of TABLE IV) were sufficiently close to the KP manager's existing schedule (column 4) to simply continue with his schedule for the implementation study. In fact his total scheduled hours were 20.5 less than the total of predicted requirements plus skeleton coverage for the hours outside of the models' time range.

In order to evaluate the scheduling algorithm, however, it was necessary to obtain requirements by period that would be both acceptable to the KP manager and provide adequate service in the DH. The figures in column 2 represent a compromise between our predicted values and the KP manager's schedule.

In the case of cooks requirements, (see TABLE V) a different situation exists. The predicted requirements are consistently lower than the schedule followed at Pease prior to the implementation study with only two exceptions. During the period 0900-1030, the predicted value is completely out of line with dining hall experience. The utilization of KPs in a cook function is very low during this period compared to other periods at Pease Main. As a consequence, the model compensates by adding more cooks than are apparently required. A similar result occurred when one compared the predicted value for this period with the observed value in the original study. The other period (1800-1900) is actually contained in the serving period associated with dinner (the evening meal). This period is treated as a period following a meal by the model. The period (1900-2000) is considered to be a skeleton requirements period and is not predicted by the model; it is also within the serving period for dinner. With respect to the dining facilities on which the models are based, this period is peculiar to Pease Main. The actual schedule followed prior to our study was used as the basis for determining requirements in these periods.

The actual schedule for cooks that was implemented for the evaluation test differed from our recommended schedule in only two periods (0730-0900 and 1600-1730). The dining hall manager wanted to change the fourth cook's schedule from 0900-1730 to 0730-1600 in order to obtain additional help during the peak breakfast load. It was our combined judgment that the lower staffing that resulted during 1600-1730 would not have a detrimental effect upon service.

IMPLEMENTATION OF SCHEDULES AND WORK STUDY

The proposed schedule for cooks (as amended to accommodate the dining hall manager's request) was implemented from 12 March through 27 March 1977. The period from 12 March through 18 March was used to familiarize personnel with the new schedule, to determine if any serious difficulties would be encountered and to have a general run-in period prior to collecting data for evaluation purposes. The period from 19 March through 27 March was used as the base period for evaluation; a work sampling study was conducted that was similar to the one conducted during the January 1976 study.

The major changes in the current work sampling study were that observation rounds were made every 15 minutes (instead of every 5 minutes) and supervisory personnel for the dining hall were not supposed to be observed unless they were performing cook or KP functions. As will be noted in TABLE VI (below), some observations were included for supervisory personnel.

TABLE VI

NUMBER OF OBSERVATIONS BY WORKER CATEGORY

	COOKS	KPs	SUPERVISOR	TOTAL
IMPLEMENTATION	2793	3121	524	6438
PRIOR STUDY	11,702	9692	3229	24,623

The differences in number of observations between the Implementation (current) study and the prior study are due to (1) the lower frequency in observation rounds, (2) fewer number of days for the current study (9 as compared to 14), and (3) the smaller number of employees observed. The number of observations are, however, adequate to obtain relative accuracy of better than 1% at the 95% confidence level for all but supervisors (this category drops to above 4% relative accuracy) [4].

EVALUATION OF RESULTS AND CONCLUSIONS

Since the scheduling algorithm and the work force estimation models are separate and independent entities, the evaluation and conclusions for each are provided in separate sections below.

SCHEDULING ALGORITHM

The scheduling algorithm performed as expected. Actually, the validation did not primarily concern the computer algorithm because given a work load and a set of admissible shifts the program will produce the mathematically optimal schedule. Thus, the major question left unanswered concerns whether or not periodic work force requirements could be estimated accurately. However, the validation test did point out some interesting aspects concerning the applicability of computer methods.

First, and most importantly, use of the algorithm can result in more efficient schedules. This was demonstrated in the case of cooks at Pease Air Force Base (one should note, however, that the scheduling problem for cooks was so simple that the optimal schedule can be, and was, generated without the use of a computerized algorithm)--see TABLE IV for results. However, use of the algorithm is only warranted when one is dealing with workers who must work regular shifts--e.g., eight-hour shifts (with or without a break for lunch) or half-time shifts and when workers must work a full week and be given consecutive days off. Then a human scheduler has difficulty developing an efficient schedule which does not make unreasonable demands on workers.

There are instances where a human scheduler can do as good or better job than the computer program. This may sound paradoxical because the computer program provides the mathematically optimal schedule. However, the computer only deals with work shifts which have some reasonable sort

of regularity. After all, if a scheduler could hire people to work for an arbitrary number of hours and not guarantee a full work week, scheduling becomes simple. One simply hires and lays off to meet demand. Thus, the computer schedule of work hours for KP workers (which guaranteed regular working hours) was slightly less efficient than the schedule that the civilian contractor developed by using several people who worked only a few hours a week at odd times. See TABLE V for a comparison of the computer generated schedule (column 3) and the KP manager's schedule (column 4). The KP manager's schedule requires 33.5 fewer paid hours to meet the estimated requirements. He benefits both from flexibility (as noted above) and from relaxing exact requirements during a given period.

Detailed employee schedules are provided in the APPENDIX: TABLE A.2 (KP Manager's Schedule); TABLE A.3 (Computerized Algorithm Schedule). TABLE A.4 describes the input data required for the computerized algorithm.

Another drawback associated with the computerized algorithm is the quality of the employee schedules that are generated (i.e., is an employee's schedule relatively uniform in the shift that he/she works and does it provide sufficient time off between shifts?). In the schedules generated for Pease Main KPs, one will note that the quality of the schedules in this regard is lacking (see TABLE A.3). Employee No. 6, for example, works shifts of 0530-1400, 0600-1430, 0930-1800, and 1030-1900 whereas employee No. 20 leaves one shift at 0230 on Thursday and returns for another shift at 0530 on the same day. The algorithm attempts to eliminate the latter problem (in this case it failed) but does not consider the former. In most cases these problems can be resolved by switching shifts among employees. This algorithm could be modified (with relative ease) to perform the switching automatically. However, varied shift patterns might still result for some employees unless one of the objectives of the

algorithm is to provide regular shifts--a modification requiring a substantial effort.

The above results suggest the proper use of the scheduling algorithm. The algorithm should be used to schedule skilled workers or other workers who, because of a union or other reason, must have regular patterns of working hours for each day of a work week. The algorithm will not be of use to a civilian contractor who can hire part time people to work irregular patterns. However, the program can be of use to the military before a contract for food service attendants is awarded. Running the program will give an upper bound on the number of attendants needed; a contractor should be able to accomplish the job with fewer employee-hours of work than that suggested by a method which guarantees regular patterns of working hours. Thus, the algorithm can be used to insure that bids are not unreasonably high.

WORK FORCE ESTIMATION MODELS

In the evaluation of the work force estimation model, four separate areas of concern are addressed:

1. Parameter Estimation

   Was it possible to obtain reliable estimates of the parameters with relative ease?

2. Management Acceptance of Predicted Results

   Was it possible to predict work force requirements (with a minimum of external considerations) that were acceptable to the appropriate managers?

3. Adequacy of Predicted Results

   Were the predicted requirements adequate during the implementation period?

4. Statistical Significance of the Models

Do the models fit the observed results?

An evaluation with respect to each of these areas are presented below.

Parameter Estimation

The parameters used in the work force estimation models are described in TABLE II in the BACKGROUND section. The estimates for the Implementation Study are presented in TABLE III along with the observed values of MEALS and KPUSE during both the present study and the earlier study of January 1976.

As is easily seen from TABLE III, the estimates for MEALS served (obtained from head counts during the period from 23 January through 22 February 1977) were very close to the observed values during the implementation study. There was, however, a significant change in the number of meals served from the original study. Head counts for meals by period appears to provide both an easy and reasonable estimate for the parameter MEALS with judgment used if changes are anticipated.

The estimates of KPUSE were not as good. Based on discussions with the KP (Civilian Contract) Manager, the Assistant KP Manager, and the dining hall managers, the observed values of KPUSE from the January 1976 study were increased by approximately 5% during each period. This produced a reliable estimate for only the 5th period (between lunch and dinner); the other estimates were low except for period 3 (between breakfast and lunch). A significant change in the values of this parameter also occurred since the original study. It is recommended that a brief work sampling study be conducted to estimate this parameter whenever a change in the aggregate KP function occurs.

The parameters MFACT and HRS are determined by the type of meal and

the duration of the serving period as explained earlier. Only HRS for the dinner meal (period 6) and period 7 (following the dinner meal) are peculiar to Pease Main. The serving period for dinner is four hours long. However, the bulk of the serving effort is accomplished in the first two hours with the next hour comparable to a cleanup period and with the last hour comparable to one with skeleton requirements. Consequently, the normal use of HRS was altered for periods 6 and 7 for this study. These parameters can be determined by examining the type of meal served at each period and by investigating the activities that take place during serving periods of unusually long duration.

Management Acceptance of Predicted Results

The predicted results in the case of KP requirements were so close to the schedule followed by the KP Manager that no change was made or attempted. Consequently, little can be said regarding these models in this area except that the predicted results were acceptable at Pease Main with the exception of the period from 0530 to 0600. This period is at the very beginning of the breakfast period and can be covered with a skeleton staff.

The predicted requirements for KPs as in TABLE IV were obtained using Models M5 and M7 with upward adjustments to include requirements that are not covered by the models; specifically, the models do not include the requirements for one KP at the Crash Kitchen, a Cashier, and an Assistant Manager. These requirements were added so that the resulting predictions would be more easily understood by all of the dining facility personnel.

The predicted results in the case of cook requirements used two fewer cooks than had been used immediately preceding the study. However, the predicted requirements were accepted at least on a trial basis. Since the

Pease Main dining hall management had agreed to cooperate for the implementation experiment, one cannot project future acceptance of proposed reductions for potentially long term commitment.

Discussion of Predicted Results

The question "Were the predicted results adequate?" could be addressed in several ways. An attitudinal survey of customers and of dining hall workers could be made before and after and the results analyzed. This, however, was outside of the scope of this study. We approached this aspect of the study through discussions with the managers of the dining hall and of the KPs and through comparisons of the work sampling data. The managers did not detect any significant effect upon service.

The observed TEMP values for both cooks and KPs are summarized in TABLE VII by day and by period of the day along with the predicted value and the number scheduled, both by period. The observed and predicted values appear to be quite reasonable for KPs as was expected. The observed vs predicted values for cooks were not as good (also expected) but are reasonable except for period 3. Comments were made on this period under PROCEDURES--it is completely out of line. The prediction for period 2 is consistently low and the prediction for period 6 is consistently high. Part of this is explained by management's choice to bring a cook on earlier than suggested and, hence, taking one off at an earlier time. This presumably shifted some of the work to be performed into an earlier period.

Another item of interest is the percent idle time by worker category. This information for both the original and the implementation studies are summarized in TABLE VIII. As can be seen, there has been a reduction in the non-productive time (hence, an increase in productive time) in every

category along with a shift in the allocation of time spent by category. The increased productive time for the supervisor has been allocated towards the preparation category which might indicate that the cook's schedule was a little tight; however, it is not known what this breakdown was immediately preceding the implementation. In the case of the worker category "Leader", a comparison with the original study is not meaningful. "Leader" in the earlier study included observations of both the KP Manager and Assistant Manager--in the implementation study, observations for these two were not included unless they were performing a KP function. The observations under"Leader"do include the leadmen's work.

The conclusion on adequacy is that the predicted requirements appeared to be quite reasonable in that service remained at essentially the same level. Also, the percent idle time was reduced when compared to the earlier results. One cannot, however, make statements regarding the situation immediately preceding the implementation.

Statistical Significance of the Models

In addition to the acceptability of the models with respect to feasibility, it is of interest to determine the extent to which the models correctly or incorrectly represent the observed productive work force requirements during the implementation study. This is addressed in this section using a Kolmogorov-Smirnov (hereafter, K-S test) Test. If more data were available, a Chi-Square Goodness of fit test could have been made as well. However, an insufficient number of cases existed so that the K-S Test was preferred.

In order to proceed with these tests, it was necessary to determine the values that occurred by day and period for the parameters KPUSE and MEALS. Three cases were examined. First, predicted TEMP values were

determined using the observed daily meal counts and aggregate observed KPUSE values during the implementation study. (Aggregate here refers to an average KPUSE value for each period during the day where all weekdays are considered to be identical). In the second case, TEMP values were calculated using observed average daily meal counts from TABLE A.1 and aggregate observed KPUSE values during the original Pease study. Finally, the third set of TEMP values are the Base predictions (see TABLE VII). For each case, a residual e_i is computed as the difference between the computed TEMP value and the observed value. These results (for both the implementation and the original Pease Main studies) are summarized in APPENDIX B, TABLES B.1-B.8. The residuals represent the amount which the predictive models fail to explain. Thus, the e_i can be considered to be the observed errors if the model is correct.

In performing the multiple linear regression analysis, certain assumptions were made concerning these errors; it is assumed that the errors are independent random variables, have zero mean, have a constant variance, and are normally distributed. Thus, if the models are "correct", or appropriate, the residuals should exhibit tendencies that confirm the assumptions, or at least, should not exhibit a denial of the assumptions. The K-S test was used to test the hypothesis that the residuals are normally distributed with zero mean and constant variance. The variance (σ^2) is taken as the estimated variance of the residuals that occurred in the development of the model being tested.

The results of the K-S test for each of the four models used in the implementation study are summarized in TABLE IX. The K-S statistic has been determined for each set of TEMP values as described above. Results are also included for each of the dining halls that were used in the development of the models (under "Original Study") so that comparisons can be made.

A brief description of the computation of the K-S statistic is given in APPENDIX B. Additional details for TABLE IX are provided in TABLES B.9 and B.10; the critical values for these tables are from tables by Hoel [5] and Massey [6].

Results are included for Pease Alert since it was used in the development of the models. However, staffing requirements are minimal and it is very unlikely that the models would apply. Also, its impact in the development of the models is small due to the small number of observations. These comments were supported by the internal validation of our earlier report and are supported here by the K-S results. The above hypothesis is accepted at the 5% level for only model M3 (the model with the lowest coefficient of determination and the poorest composite results for the four major dining facilities).

If one omits Pease Alert (per above), models M1, M5, and M7 appear to be acceptable with respect to the K-S test applied to the original study (internal validation). The same is not true for model M3. The periods covered by this model (between meals) are ones in which the workers (cooks) have more flexibility in what they do and when they do it.

The tests for the implementation study support the hypothesis for only model M7 (KPs between meal periods). This result may be due to the fact that the only parameter used in this model is MEALS; the other three models use KPUSE (M5) and MFACT and HOURS (M1 and M3). The primary difference in the three cases examined under "Implementation" is in the value used for KPUSE. MFACT and HOURS are the same in each case; and, although MEALS varies, its average value in each case is essentially unchanged. KPUSE values for each case are approximately as follows:

Case 2: observed values (aggregate) during the original study by period

Case 3: Case 2 values plus 5% and rounded to nearest multiple of 5

TABLE VII

TEMP VALUES FOR COOKS: BASE PREDICTIONS AND SCHEDULED VS OBSERVED BY DAY AND PERIOD FOR WEEKDAYS

PERIOD:	1	2	3	4	5	6
DAY						
MON	3.00	3.67	4.17	4.29	3.83	2.68
TUES	2.00	3.60	3.50	3.79	3.33	2.06
WED	*	2.86	3.00	3.00	2.67	1.67
THURS	*	3.50	3.67	4.21	3.17	2.21
FRI	1.00	4.20	4.00	4.43	3.33	2.11
PREDICTED	2.92	2.15	7.34	5.16	3.60	3.81
USING ROUNDING TABLE	3	3	7	5	4	4
NUMBER SCHEDULED	1	3.5	4	5	4	3

* No observations

VS OBSERVED BY DAY AND PERIOD

PERIOD:	2	3	4	5	6	7
DAY						
MON	4.17	4.83	8.15	5.83	4.50	4.75
TUES	4.00	5.00	7.86	4.83	5.00	5.50
WED	3.58	4.67	7.71	5.00	4.00	6.25
THURS	4.25	2.67	6.79	3.33	3.30	4.50
FRI	4.00	3.00	7.07	6.33	4.70	5.50
PREDICTED	5.04	3.90	7.60	6.82	5.88	5.53
USING ROUNDING TABLE	5	4	8	7	6	6
NUMBER SCHEDULED	5	4	9	7	6	6

TABLE VIII

WORK ACTIVITY (%) FOR TYPE OF WORKER

PEASE MAIN ORIGINAL STUDY

	WORK ACTIVITY (%)					
TYPE OF WORKER	PREP.	SERVE	SAN.	SUPPLY	SUPER.	NON PROD.
SUPERVISOR	4.9	3.8	.9	3.2	35.1	52.2
COOKS	26.9	18.9	4.2	1.5	7.7	40.8
LEADER	3.7	4.4	12.7	1.3	26.1	51.8
K.P.	7.0	8.8	52.3	.2	.9	30.8

PEASE MAIN IMPLEMENTATION

	WORK ACTIVITY (%)					
TYPE OF WORKER	PREP.	SERVE	SAN.	SUPPLY	SUPER.	NON PROD.
SUPERVISOR	15.9	4.1	1.5	1.0	35.6	42.0
COOKS	34.2	14.9	2.3	2.1	13.7	32.8
LEADER	4.5	9.0	59.7	0	11.9	14.9
K.P.	6.3	21.0	45.7	.3	1.2	25.4

TABLE IX

SUMMARY OF KOLMOGOROV-SMIRNOV TESTS: Predictive Models for Weekdays

	Significance Level (in percent) by Model			
	Cooks		KPs	
Dining Facility	M1(During)	M3(Between)	M5(During)	M7(Between)
Implementation Study				
Pease Main: 1*	--	1	--	5
2*	--	--	10	10
3*	1	--	--	5
Original Study				
Pease Main	1	--	10	10
Devens 649	1	--	1	10
Devens 694	10	10	1	10
Newport	10	1	10	1
Pease Alert	--	5	--	--

*The values provided under Implementation arise from considering three different cases, each case related to the values used for KPUSE and MEALS as follows:

1. KPUSE--Aggregate by period from Implementation (TABLE A.6)
   MEALS--Meal count by both period and day from Implementation (TABLE A.7)
2. KPUSE--Aggregate by period from Original (TABLE A.6)
   MEALS--Average meal count by both period and day from BASE period (TABLE A.1)
3. KPUSE--BASE values by period (TABLE III)
   MEALS--Average by period (TABLE III)

Case 1: observed values (aggregate) during the implementation study by period; these were approximately Case 2 values plus 15% during serving periods and Case 2 values during non-serving periods.

Consequently, the three cases provide a type of sensitivity analysis for KPUSE. The fact that the hypothesis was accepted at the 10% level for M5, Case 2, may be an indication that KPUSE is a measurement of managerial attributes rather than the utilization of KPs in a cook's function. Although this cannot be supported in a rigorous way, the following observations can be made:

- M5 has the form KPs= a + b · MEALS + C · KPUSE whereas M1 and M3 include KPUSE in interaction terms.
- The management of food service and the KPs were the same in both the original and the implementation studies.
- In the original study, the values for KPUSE were low at Devens 649 and 694, medium at Pease Main, and high at Newport so that they could correspond to a rank order rather than a percent utilization.

As discussed later in future work, we believe that this parameter (KPUSE) should be examined further, either via a different approach--analyzing the existing data in an attempt to predict work load content by type of function rather than by type of worker--or to obtain additional data over a wider range of the values for the parameter.

FUTURE RESEARCH

There are two aspects to the research reported in this document; the development of a method to estimate work force needs, and the development of a computer program to schedule workers to meet the forecasted needs most efficiently. The following candidates for future work are listed below in priority order and discussed in more detail below.

	Task	Effort
1.	Re-analyze the data in terms of tasks rather than types of workers.	3 man months
2.	Collect data from wider sample of dining facilities	uncertain
3.	Refine estimation model.	3 man months
4.	Evaluate facilities nation-wide	uncertain
5.	Production smoothing	uncertain
6.	Refine scheduling algorithm	3-9 man months

Although further work on the scheduling algorithm is not recommended with high priority we lead off the discussion with this topic.

FUTURE WORK ON SCHEDULING ALGORITHMS

There are a number of improvements which could be made to the scheduling algorithm. These were discussed in our earlier report and mainly concerned enabling the program to accept more irregular and fragmented workshift patterns. In our opinion, however, these additions would be only of marginal use. Consequently, we do not believe that improvements to an already good algorithm should have the highest priority in future research programs.

There is, however, an important effort which should take place with respect to the scheduling algorithm. More applications for its use should be sought. The importance of efficient scheduling in food service operations has been well documented. However, there undoubtedly are work force

scheduling problems in other areas of DOD which could benefit from an efficient, easy-to-use scheduling algorithm. Also, the algorithm could be used in conjunction with the estimation models to guide the awarding of contracts as described below.

FUTURE WORK ON METHODS TO ESTIMATE WORK FORCE REQUIREMENTS

As discussed in the section on results, the models to predict periodic manpower requirements have a limited accuracy especially in predicting work requirements. There are a number of approaches which could be taken which would improve their accuracy and reliability. These alternative approaches will be outlined below and then the most promising avenue for use of the models developed will be described in some detail.

Potentially, the easiest way to increase the accuracy of the models is to modify the manner in which the data were analyzed. Since it was initially believed that most food service attendants did one class of jobs and cooks another, the models attempt to predict the number of each type of worker. Actually, KPs do varying amounts of cook-type work. Consequently, more accuracy in the models might be obtained if they tried to predict the amount of time needed for tasks rather than for types of worker. Then, the work force requirements could be constructed taking into account what sorts of tasks each type of worker does at a particular facility.

We intend to reorganize and re-analyze the data according to tasks as time permits and will inform you of the results when they are available.

Another obvious way to improve the model's performance is to include more factors in the descriptive model by 1) collecting the data from more facilities and 2) collecting more detailed data from the individual facilities. We will first discuss the second alternative.

It is possible to collect more detailed data, for example data on scheduling philosophies of the managers, the time required to perform operations by menu item, and the time required to perform isolated sanitation tasks. However, there is some question as to how much the accuracy will be improved. This is because there is a great deal of latitude when certain tasks, especially preparation for future meals, can be done. Thus, in order to predict period by period demand accurately, it would be necessary to have the work schedule as a variable. Since work schedules can vary from day to day, and are a function of who is managing the operation, it is very difficult and not practical to include it as a variable--unless the Natick Labs wish to develop normative procedures for scheduling or "smoothing" work throughout the day. This is a definite possibility and is discussed in a later section as it represents an entirely separate project. It could use some of the data collected but would require both a different analysis procedure and skilled cooks as working members of the research team.

The alternative of collecting data from more facilities appears to us to have a high priority. However, we do not recommend collecting the large quantity of detailed data from each facility as we have done in the past. We have seen that even detailed data are probably not adequate to describe hourly demand levels unless complex and expensive to estimate parameters are used. Therefore, before describing what additional data might be advisable to collect, we should describe the ultimate form and use of the work force prediction model.

Although variations in work schedules make it difficult to predict accurately hour by hour a period by period demand (especially between

meals) it is less difficult to predict average staffing levels. After all, the job must be done sometime during the work day. Therefore, the models have great potential to estimate the general level of work force needed in any given dining facility.

Because of their general predictive power the models should be used to evaluate the efficiency of manpower usage in all dining facilities across the country. The models can augment present methods of deciding whether or not a facility is making inefficient use of its work force and if it has, in aggregate, too many workers.

Also, model predictions could be used to set ceilings on contract requirements of labor costs.If a facility were using significantly more workers than the models predictions, facility managers (or contractors) should be able to show cause for the discrepancy. If there were a justificable reason for the discrepancy, that factor could be incorporated in the model for future use. In fact, since the models should be used on a periodic basis (perhaps yearly or bi-yearly in each facility) the continuing collection of data could serve to augment and constantly refine the models.

The models can be used now on many facilities. The main variables not contained in the analysis procedures are the general type of food preparation technique (we have no data on facilities which serve food primarily prepared in a central facility). We also need more data that cover wider ranges of values for the model parameters. Therefore, the current models could not be expected to predict appropriate workloads on the above types of facilities until some experience has been gained. However, large data collection efforts would not be required.

The specific proposal for the continued use of the models are outlined below:

1. A small team be formed consisting of one or two individuals who constructed the models and one or two Natick employees.
2. This team apply the model to a stratified sample of facilities. About four facilities at each of five bases should suffice.
3. Model predictions are to be compared with actual staffing levels.
4. Spot data checks (work sampling) be taken at each base. One or at most two individuals could collect the required data.
5. The models should be refined based on the data collected.
6. The above research team should train evaluators who would take over the work force evaluation for essentially all facilities or classes of facilities.

The above work could commence in September of 1978.

PRODUCTION SMOOTHING

The data collected exhibited a large variation in work load during a typical day. Certainly some of the "ups-and-downs" are unavoidable. However, it is the belief of the research team that the peaks and valleys of work load could be leveled somewhat.

We suggest that a brief (2-3 week) survey be conducted by a team which would include an experienced chef, food service attendant, and operations research analysis. This survey would determine the incentives for a full scale study.

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APPENDIX A

SUPPORTING TABLES

TABLE A.1

NUMBER OF MEALS SERVED FROM 23 JANUARY THROUGH 22 FEBRUARY 1977

DAY AND DATE		MIDNIGHT	BREAKFAST	LUNCH	DINNER
SAT	29 Jan	109	198	351	192
	5 Feb	58	104		315
	12 Feb	216	145		496
	19 Feb	63	82		267
Average*		60.5	124.5	--	291
SUN	23 Jan	62	111		341
	30 Jan	77	107		344
	6 Feb	55	125		393
	13 Feb	32	126		500
	20 Feb	37	75		342
Average*		52.5	117.25	--	359.33
MON	24 Jan	43	86		347
	31 Jan	49	124		399
	7 Feb	51	147	387	326
	14 Feb	53	152	427	331
	21 Feb	53	86		394
Average *		49.8	149.5	407	328.5
TUES	25 Jan	61	97		400
	1 Feb	69	163	395	286
	8 Feb	106	187	424	353
	15 Feb	88	165	411	266
	22 Feb	51	141	397	350
Average*		75	164	406.75	313.75
WED	26 Jan	51	164	468	399
	2 Feb	67	158	410	289
	9 Feb	115	162	435	318
	16 Feb	90	183	414	261
Average*		80.75	166.75	419.67	289.33

TABLE A.1
(continued)

DAY AND DATE		MIDNIGHT	BREAKFAST	LUNCH	DINNER
THURS	27 Jan	81	190	499	368
	3 Feb	65	138	399	318
	10 Feb	82	180	410	344
	17 Feb	77	143	383	231
Average*		76.25	162.75	397.33	315.25
FRI	28 Jan	83	203	460	342
	4 Feb	87	157	368	226
	11 Feb	86	287	352	295
	18 Feb	--	173	392	244
Average*		85.33	205	370.67	276.75
WEEKEND Avg.		54.86	119.67	--	333.67
WEEKDAY Avg.		71.81	171.83	400.27	298.75

*Underlined values excluded in computing averages; some are excluded because they are extreme values and some are excluded because a normal schedule for the day was not followed (Jan 24, 25, 29 & 31 and Feb 21)

TABLE A.2

SUMMARY OF KP MANAGER EMPLOYEE SCHEDULE

Employee No.	Hours		Days Worked	Total Hours (paid)
1 (Lead Man)	0600-1430		Tues-Sat	40
2 (Lead Man)	0530-1400		Sun-Thurs	40
3	0600-1430		Tues-Sat	40
4	0600-1430		Mon-Fri	40
5	0600-1430		Fri-Tues	40
6	0600-1430		Mon, Wed, Sat, Sun	32
	1030-1900		Tues	8
7	0600-1000		Mon, Thurs, Fri	12
	0600-1430		Sun	8
	1030-1900		Sat	8
8	0600-1430		Sat, Sun	16
	1030-1900		Mon, Fri	16
9L	1800-0230		Sun-Thurs	40
10	1700-2000		Tues-Fri	12
	2200-0230		Tues-Sat	22½
11	2200-0230		Mon	4½
	1800-0230		Fri	8
	1900-0130		Sat	6½
	2200-0230		Sun	4½
12 (Asst. Mgr.)	1030-1900	*	Mon-Fri	40 (Sal.)
13 (Lead Man and Asst. Mgr. on weekends)	1030-1900		Wed-Sun	40 (Sal.)
14	1030-1900		Sun-Thurs	40
15	1130-2000		Mon	8
	1030-1900		Tues-Fri	32
16	1030-1900		Sun-Thurs	40
17	1130-2000		Mon	8
	1030-1900		Tues-Fri	32
18	1030-1900		Sat, Sun	16
19	1030-1900		Sat, Sun	16
20	1430-1900		Fri	4

TABLE A.2
(continued)

Employee No.	Hours		Days Worked	Total Hours (paid)
20	1030-1900		Sat	8
21	0600-1430	*	Mon-Fri (Cashier)	40
22	0900-1730	*	Mon-Fri (Crash Kitch)	40
23	1500-2000	*	Mon-Fri (Cashier)	25
	2300-0200	*	Mon-Fri (Cashier)	15

*Requirements for these employees are not determined by the predictive model.

TABLE A.3

SUMMARY OF ALGORITHM SCHEDULE FOR KPs

Employee No.	Hours	Days Worked	Total Hours (paid)
1	0530-1400	Wed-Fri	
	0600-1430	Sat, Sun	40
2	0600-1430	Wed-Sun	40
3	0530-1400	Mon	
	0600-1430	Thurs-Sun	40
4	0600-1430	Thurs-Mon	40
5	0600-1430	Sat-Mon	
	0930-1800	Thurs, Fri	40
6	0930-1800	Sat, Sun	
	0500-1430	Mon	
	0530-1400	Tues	
	1030-1900	Fri	40
7	0930-1800	Mon	
	0600-1430	Tues	
	1030-1900	Fri-Sun	40
8	1030-1900	Sat-Mon	
	0600-1430	Tues, Wed	40
9	1030-1900	Sat-Mon	
	0600-1430	Tues, Wed	40
10	1030-1900	Sun, Mon, Thurs	
	0930-1800	Tues, Wed	40
11	1030-1900	Mon, Thurs	
	1000-1830	Tues, Wed	
	1800-0230	Sun	40
12	1030-1900	Mon-Fri	40
13	1030-1900	Mon-Fri	40
14	1030-1900	Mon-Fri	40
15	1800-0230	Mon	
	1030-1900	Tues-Fri	40
16	1800-0230	Mon	
	1030-1900	Tues-Fri	40

TABLE A.3
(continued)

Employee No.	Hours	Days Worked	Total Hours (paid)
17	1800-0230	Mon, Thurs, Fri	
	1030-1900	Tues, Wed	40
18	0530-1400	Mon	
	1800-0230	Tues-Fri	40
19	1800-0230	Tues-Fri	
	1030-1900	Sat	40
20	1800-0230	Tues, Wed, Sat	
	0530-1400	Thurs, Fri	40
21	0600-1000	Mon	
	0530-0930	Tues, Wed	
	2200-0200	Sat, Sun	20
22	0600-1000	Tues-Sat	20

TABLE A.4

SUMMARY OF INPUT FOR SCHEDULING ALGORITHM FOR KPs

	Weekday		Weekend	
Time	Hour	Requirements	Hour	Requirements
0530-0600	1	2		
0600-0700	2	6	1	5
0700-0800	3	6	2	5
0800-0930	4	6	3	5
0930-1030	5	6	4	5
1030-1130	6	12	5	10
1130-1300	7	12	6	10
1300-1400	8	12	7	10
1400-1430	9	9	8	10
1430-1530	10	8	9	5
1530-1700	11	8	10	5
1700-1800	12	8	11	5
1800-1900	13	8	12	5
1900-2000	14	3	13	1
2000-2100	15	1	14	1
2100-2200	16	1	15	1
2200-2300	17	2	16	2
2300-2400	18	3	17	2
2400-0130	19	3	18	2
0130-0200	20	3	19	1*
0200-0230	21	2		

*Hour 19 is assumed to be 0130-0230 on weekends.

TABLE A.5

SUMMARY OF COOKS SCHEDULES

PRIOR TO IMPLEMENTATION STUDY

Military Cooks consist of two teams ;

Team A, 4 cooks, follow a days work pattern of 3 on, 3 off, 2 on, 2 off.

Team B, 3 cooks, follow a days work pattern of 3 off, 3 on, 2 off, 2 on.

TEAM A	SCHEDULE
Cook A1	0530-1800
Cook A2	0530-1800
Cook A3	0530-1800
Cook A4	1730-0600

TEAM B	SCHEDULE
Cook B1	0530-1800
Cook B2	0530-1800
Cook B3	1730-0600

Civilian Cooks (4)	SCHEDULE	
Cook C1	0530-1400	Mon-Fri
Cook C2	0530-1400	Mon-Fri
Cook C3	1030-1900	Tue-Sat
Cook C4	1030-1900	Sun-Thur

DURING IMPLEMENTATION

Military Cooks consist of two teams with 3 cooks each.

Same days work pattern as above.

TEAM A & B	SCHEDULE
Cook A1 or B1	0530-1800
Cook A2 or B2	0530-1800
Cook A3 or B3	1730-0600

Civilian Cooks (3)	SCHEDULE	
Cook C1	0530-1400	Mon-Fri
Cook C2	0730-1600	Mon-Fri
Cook C3	1030-1900	Mon-Fri

TABLE A.6

KPUSE VALUES

OBSERVED BY DAY AT PEASE IMPLEMENTATION STUDY

Day	Period 2	3	4	5	6	7
MON	39.6	0	35.7	25.7	33.3	26.3
TUES	39.3	3.3	40.9	34.5	40.0	27.3
WED	44.5	0	28.7	33.3	40.0	24.0
THURS	32.7	31.3	34.8	10.0	33.3	33.3
FRI	39.3	0	41.5	15.8	31.9	18.2
AGGREGATE OVER WEEKDAYS	38.9	4.9	36.3	24.3	35.5	25.5

OBSERVED BY DAY AT PEASE ORIGINAL STUDY

Day	Period 2	3	4	5	6	7
MON	28.6	13.8	29.2	15.0	13.8	4.5
TUES	22.3	10.0	22.4	32.5	21.0	14.9
WED	27.4	4.8	14.9	22.9	7.7	3.3
THURS	25.6	0.0	14.2	20.9	19.6	5.3
FRI	22.8	1.0	23.1	17.3	23.2	11.1
AGGREGATE OVER WEEKDAYS	25.1	5.6	20.6	22.2	17.8	7.4

TABLE A.7

PEASE IMPLEMENTATION
OBSERVED DAILY MEAL COUNTS

	MIDNIGHT	BREAKFAST	LUNCH	DINNER
MONDAY, MARCH 21, 1977	87	155	411	324
TUESDAY	85	200	404	320
WEDNESDAY	83	168	371	321
THURSDAY	86	165	418	307
FRIDAY	29	147	426	220

APPENDIX B

KOLMOGOROV-SMIRNOV STATISTIC
and
TABLE OF RESIDUALS

BRIEF DESCRIPTION OF THE KOLMOGOROV-SMIRNOV STATISTIC

In using the Kolmogorov-Smirnov test (see Ang and Tang [7]), an experimental distribution function is obtained from the observed data as follows:

- Let $X_1, X_2, \ldots, X_n$ be the observed data where

  $X_i \leq X_{i+1}$ $(i=1, \ldots, n-1)$ and n is the sample size.

- The stepwise experimental distribution function is given by

$$S_n(X) = \begin{cases} 0 & X < X_1 \text{ (the smallest observed value)} \\ \frac{k}{n} & X_k \leq X < X_{k+1} \\ 1 & X \geq X_n \text{ (the largest observed value)} \end{cases}$$

Using the experimental distribution function $S_n(X)$ and the theoretical distribution function $F(X)$, where X is $N(0, \sigma^2)$ in our experiment, a random variable D_n is computed as

$$D_n = \max_X \left| F(X) - S_n(X) \right|.$$

The K-S Test compares the observed value for D_n with the critical value D_n^{α}, where

$$P(D_n \leq D_n^{\alpha}) = 1-\alpha.$$

TABLE B.1

OBSERVED, PREDICTED TEMP VALUES AND RESIDUALS--PEASE IMPLEMENTATION
COOKS WEEKDAY SERVING PERIODS

DAY	PERIOD	OBSERVED TEMP	PREDICTIONS PRED 1	PRED 2	PRED 3	RESIDUALS RES 1	RES 2	RES 3
3	2	3.67	.36	2.77	2.15	3.31	.9	1.52
3	4	4.29	2.27	6.57	5.16	2.02	-2.28	- .87
3	6	2.68	3.13	3.95	3.81	- .45	-1.27	-1.13
4	2	3.60	.46	2.86	2.15	3.14	.74	1.45
4	4	3.79	2.23	6.57	5.16	1.56	-2.78	-1.37
4	6	2.06	3.12	3.90	3.81	-1.06	-1.84	-1.75
5	2	2.86	.39	2.88	2.15	2.47	- .02	.71
5	4	3.00	2.04	6.71	5.16	.96	-3.71	-2.16
5	6	1.67	3.12	3.82	3.81	-1.45	-2.15	-2.14
6	2	3.50	.38	2.86	2.15	3.12	.64	1.35
6	4	4.21	2.31	6.49	5.16	1.90	-2.28	- .95
6	6	2.21	3.09	3.91	3.81	- .88	-1.7	-1.60
7	2	4.20	.34	3.13	2.15	3.86	1.07	2.05
7	4	4.43	2.36	6.16	5.16	2.07	-1.73	- .73
7	6	2.11	2.90	3.78	3.81	- .79	-1.67	-1.70
					μ	1.32	-1.21	- .49
					σ	1.805	1.495	1.475

PRED1 = Predicted values of TEMP using observed daily meal counts and aggregate observed KPUSE values during the implementation study.

PRED2 = Predicted values of TEMP using observed average daily meal counts from Table A.1 and aggregate observed KPUSE values during the original Pease study.

PRED3 = Base predictions (see Table III).

RES1 = TEMP-PRED1

RES2 = TEMP-PRED2

RES3 = TEMP=PRED3

TABLE B.2

OBSERVED, PREDICTED TEMP VALUES AND RESIDUALS--PEASE IMPLEMENTATION
KP WEEKDAYS SERVING PERIODS

		OBSERVED	PREDICTIONS			RESIDUALS		
DAY	PERIOD	TEMP	PRED 1	PRED 2	PRED 3	RES 1	RES 2	RES 3
3	2	4.17	5.60	4.33	5.04	-1.43	- .16	- .87
3	4	8.15	8.52	7.26	7.60	- .37	.89	.55
3	6	4.50	7.39	6.24	5.88	-2.89	-1.74	1.38
4	2	4.00	6.19	4.51	5.04	-2.19	- .51	-1.04
4	4	7.86	8.43	7.26	7.60	- .57	.60	.26
4	6	5.00	7.34	6.05	5.88	-2.34	-1.05	- .88
5	2	3.58	5.77	4.55	5.04	-2.19	- .97	-1.46
5	4	7.71	8.00	7.42	7.60	- .29	.29	.11
5	6	4.00	7.35	5.73	5.88	-3.35	-1.73	-1.88
6	2	4.25	5.73	4.50	5.04	-1.48	- .25	- .79
6	4	6.79	8.61	7.13	7.60	-1.82	- .34	- .81
6	6	3.30	7.17	6.07	5.88	-3.87	-2.77	-2.58
7	2	4.00	5.50	5.04	5.04	-1.50	-1.04	-1.04
7	4	7.07	8.71	6.79	7.60	-1.64	.28	- .53
7	6	4.70	6.04	5.57	5.88	-1.34	- .87	-1.18
					$\mu=$	1.8	-.62	- .90
					$\sigma=$	1.03	.98	.80

PRED1 = Predicted values of TEMP using observed daily meal counts and aggregate observed KPUSE values during the implementation study.

PRED2 = Predicted values of TEMP using observed average daily meal counts from Table A.1 and aggregate observed KPUSE values during the original Pease study.

PRED3 = Base predictions (see Table III).

RES1 = TEMP-PRED1

RES2 = TEMP-PRED2
RES3 = TEMP-PRED3

TABLE B.3

OBSERVED, PREDICTED TEMP VALUES AND RESIDUALS--PEASE IMPLEMENTATION

COOKS WEEKDAYS NON-SERVING PERIODS

		OBSERVED	PREDICTIONS			RESIDUALS		
DAY	PERIOD	TEMP	PRED 1	PRED 2	PRED 3	RES 1	RES 2	RES 3
3	1	3.00	2.78	2.74	2.92	.22	.26	.08
3	3	4.17	7.82	7.79	7.34	-3.65	-3.62	-3.17
3	5	3.83	3.71	3.76	3.60	.12	.07	.23
4	1	2.00	3.15	2.86	2.92	-1.15	- .86	- .92
4	3	3.50	7.71	7.78	7.34	-4.21	-4.28	-3.84
4	5	3.33	3.71	3.66	3.60	- .38	- .33	- .27
5	1	--	--	--	--	--	--	--
5	3	3.00	7.52	7.86	7.34	-4.52	-4.86	-4.34
5	5	2.67	3.89	3.42	3.60	-1.22	- .75	- .93
6	1	--	--	--	--	--	--	--
6	3	3.67	7.85	7.71	7.34	-4.18	-4.04	-3.67
6	5	3.17	3.55	3.71	3.60	- .38	- .54	- .43
7	1	1.00	2.72	3.19	2.92	-1.72	-2.19	-1.92
7	3	4.00	7.93	7.47	7.34	-3.93	-3.47	-3.34
7	5	3.33	2.90	3.58	3.60	.43	- .25	- .27
					μ=	-1.89	-1.91	-1.75
					σ=	1.92	1.88	1.69

TABLE B.4

OBSERVED, PREDICTED TEMP VALUES AND RESIDUALS--PEASE IMPLEMENTATION

KP WEEKDAYS NON-SERVING PERIODS

OBSERVED			PREDICTIONS			RESIDUALS		
DAY	PERIOD	TEMP	PRED 1	PRED 2	PRED 3	RES 1	RES 2	RES 3
3	3	4.83	3.68	3.61	3.90	1.15	1.22	.93
3	5	5.83	6.95	6.90	6.82	-1.12	-1.07	- .99
3	7	4.75	5.84	5.90	5.53	1.09	-1.15	- .78
4	3	5.00	4.26	3.80	3.90	.74	1.20	1.10
4	5	4.83	6.86	6.90	6.82	-2.03	-2.07	-1.99
4	7	5.50	5.79	5.71	5.53	- .29	- .21	- .03
5	3	4.67	3.85	3.83	3.90	.82	.84	.77
5	5	5.00	6.44	7.07	6.82	-1.44	-2.07	-1.82
5	7	6.25	5.80	5.40	5.53	.45	.85	.72
6	3	2.67	3.81	3.78	3.90	-1.14	-1.11	-1.23
6	5	3.33	7.04	6.78	6.82	-3.71	-3.45	-3.49
6	7	4.50	5.62	5.73	5.53	-1.12	-1.23	-1.03
7	3	3.00	3.58	4.32	3.90	- .58	-1.32	- .90
7	5	6.33	7.15	6.44	6.82	- .82	- .11	- .49
7	7	5.50	4.51	5.24	5.53	.99	.26	- .03
					μ=	-4.67	-.628	-.617
					σ=	1.376	1.363	1.26

TABLE B.5

PEASE ORIGINAL STUDY

KP WEEKDAYS SERVING PERIOD

DAY	PERIOD	OBSERVED TEMP	PREDICTION	RESIDUAL TEMP--PRED
3	4	9.94	8.27	1.67
3	6	6.12	6.68	- .56
4	2	6.42	6.35	.07
4	4	8.80	7.89	.91
4	6	4.86	6.86	-2.00
5	2	6.12	6.04	.08
5	4	9.51	8.31	1.20
5	6	2.23	3.72	-1.49
6	2	5.89	6.09	- .20
6	4	8.91	7.96	.95
6	6	5.70	6.66	.96
7	2	5.89	5.65	.24
7	4	8.54	7.92	.62
10	2	5.61	5.58	.03
10	4	10.77	8.46	2.31
10	6	6.22	7.16	- .94
11	2	6.51	6.25	.26
11	4	9.81	8.32	1.49
11	6	6.49	7.26	- .77
12	4	9.81	9.31	.50
12	6	6.25	7.65	-1.40
13	2	6.45	6.56	- .11
13	4	9.57	8.32	1.25
13	6	6.72	7.07	- .35
14	4	9.60	6.87	2.73
14	6	5.27	5.74	- .47
			$\mu =$	.268
			$\sigma =$	1.144

TABLE B.6

PEASE ORIGINAL STUDY

COOKS WEEKDAYS SERVING PERIOD

DAY	PERIOD	OBSERVED TEMP	PREDICTION	RESIDUAL TEMP--PRED
3	4	5.38	7.45	-2.07
3	6	3.50	4.07	- .57
4	2	5.37	3.78	1.59
4	4	6.82	7.12	- .30
4	6	3.57	4.11	- .54
5	2	4.56	3.63	.93
5	4	5.94	7.49	-1.55
6	2	5.33	3.65	1.68
6	4	6.33	7.18	- .85
6	6	3.72	4.06	- .34
7	2	5.26	3.43	1.83
7	4	6.30	7.15	- .85
10	2	4.67	3.39	1.28
10	4	5.96	7.62	-1.66
10	6	3.87	4.19	- .32
11	2	5.02	3.73	1.30
11	4	6.66	7.50	- .84
11	6	4.35	4.22	.13
12	4	6.31	8.36	-2.05
12	6	3.64	4.32	- .68
13	2	4.95	3.88	1.06
13	4	6.81	7.50	- .69
13	6	3.83	4.17	- .34
14	4	5.83	6.23	- .40
14	6	3.32	3.82	- .50
			μ=	0.19
			σ=	1.142

TABLE B.7

PEASE ORIGINAL STUDY

KP WEEKDAYS NON-SERVING PERIODS

DAY	PERIOD	OBSERVED TEMP	PREDICTION	RESIDUAL TEMP--PRED
3	5	6.13	7.90	-1.77
3	7	5.58	6.33	- .75
4	3	6.53	5.61	.92
4	5	5.66	7.53	-1.87
4	7	5.37	6.51	-1.14
5	3	6.04	5.30	.74
6	3	6.26	5.36	.90
6	5	5.53	7.59	2.06
6	7	5.33	6.31	- .98
7	3	5.84	4.92	.92
10	3	6.32	4.84	1.48
10	5	5.22	8.09	2.87
10	7	6.42	6.80	.38
11	3	6.69	5.51	1.18
11	5	6.81	7.95	-1.14
11	7	7.00	6.90	.10
12	5	6.33	8.92	-2.59
12	7	5.77	7.29	-1.52
13	3	6.79	5.82	.97
13	5	6.60	7.95	-1.35
13	7	6.51	6.71	- .20
14	5	5.56	6.52	- .96
14	7	7.00	5.41	-1.59
			μ =	-.145
			σ =	1.427

TABLE B.8

PEASE ORIGINAL STUDY

COOKS WEEKDAYS NON-SERVING PERIODS

DAY	PERIOD	OBSERVED TEMP	PREDICTION	RESIDUAL TEMP--PRED
3	5	3.51	4.23	- .72
4	1	3.33	4.00	- .67
4	3	5.53	7.95	-2.42
4	5	3.96	4.44	- .48
5	1	2.67	3.81	-1.14
5	3	5.58	8.20	-2.62
6	1	2.53	3.84	-1.31
6	3	4.38	8.01	-3.63
6	5	3.78	4.32	- .54
7	1	2.00	3.56	-1.56
7	3	5.11	8.03	2.72
10	1	2.20	3.52	-1.32
10	3	5.50	8.33	-2.83
10	5	4.05	4.43	- .38
11	1	1.67	3.94	-2.27
11	3	5.31	8.19	2.88
11	5	4.74	4.53	.21
12	5	4.48	4.43	.05
13	1	4.00	4.13	- .13
13	3	5.33	8.16	-2.83
13	5	4.08	4.42	- .34
14	5	4.19	4.16	.03
			μ=	-.837
			σ=	1.65

TABLE B.9

Summary of Kolmogorov-Smirnov Tests: Predictive Models for KPs on Weekdays

Model	Dining Hall	Number of Observations	D_n	D_n^α α=0.01	D_n^α α=0.05	D_n^α α=0.10	Significance Level
M5 (during meal periods), α=1.173							
	Pease Main						
	Original Study	26	0.0523	0.319	0.267	0.239	0.10
	Implementation:* 1	15	0.6729	0.404	0.338	0.304	--
	2		0.2890				0.10
	3		0.4819				--
	Pease Alert	19	0.3921	0.363	0.301	0.272	--
	Devens 649	26	0.2745	0.319	0.267	0.239	0.01
	Devens 694	27	0.2850	0.314	0.262	0.235	0.01
	Newport	26	0.1946	0.319	0.267	0.239	0.10
M7 (between meal periods), α=2.312							
	Pease Main						
	Original Study	23	0.2451	0.3399	0.2836	0.2544	0.10
	Implementation:* 1	15	0.3085	0.404	0.338	0.304	0.05
	2		0.2981				0.10
	3		0.3156				0.05
	Pease Alert	15	0.4480	0.404	0.338	0.304	--
	Devens 649	28	0.1303	0.308	0.257	0.231	0.10
	Devens 694	27	0.1648	0.314	0.262	0.235	0.10
	Newport	24	0.3287	0.333	0.278	0.249	0.01

*The values provided under Implementation arise from considering three different cases, each case related to the values used for KPUSE and MEALS as follows:

1. KPUSE--Aggregate by period from Implementation (TABLE A.6)
   MEALS--Meal count by both period and day from Implementation (TABLE A.7)

2. KPUSE--Aggregate by period from Original (TABLE A.6)
   MEALS--Average meal count by both period and day from BASE period (TABLE A.1)

3. KPUSE--BASE values by period (TABLE III)
   MEALS--Average by period (TABLE III)

TABLE B.10

Summary of Kolmogorov-Smirnov Tests: Predictive Models for Cooks on Weekdays

Model	Dining Hall		Number of Observations	D_n	D_n^α α=0.01	D_n^α α=0.05	D_n^α α=0.10	Significance Level
M1 (during meal periods), α=1.259								
	Pease Main							
	Original Study		25	0.2787	0.32	0.27	0.24	0.01
	Implementation*:	1	15	0.4240	0.404	0.338	0.304	--
		2		0.5104				--
		3		0.3857				0.01
	Pease Alert		18	0.4486	0.371	0.309	0.278	--
	Devens 649		26	0.2768	0.319	0.267	0.239	0.01
	Devens 694		27	0.1376	0.314	0.262	0.235	0.10
	Newport		26	0.1393	0.319	0.267	0.239	0.10
M3 (between meal periods), α=1.558								
	Pease Main							
	Original Study		22	0.4385	0.348	0.290	0.260	--
	Implementation*:	1	13	0.3897	0.433	0.361	0.325	0.01
		2		0.8331				--
		3		0.4430				--
	Pease Alert		21	0.2717	0.356	0.297	0.266	0.05
	Devens 649		28	0.3254	0.308	0.257	0.231	--
	Devens 694		29	0.1427	0.308	0.252	0.227	0.10
	Newport		23	0.3259	0.340	0.284	0.254	0.01

*The values provided under Implementation arise from considering three different cases, each case related to the values used for KPUSE and MEALS as follows:

1. KPUSE--Aggregate by period from Implementation (TABLE A.6)
   MEALS--Meal count by both period and day from Implementation (TABLE A.7)

2. KPUSE--Aggregate by period from Original (TABLE A.6)
   MEALS--Average meal count by both period and day from BASE period (TABLE A.1)

3. KPUSE--BASE values by period (TABLE III)
   MEALS--Average by period (TABLE III)